Control and Design of Microgrid Components

Final Project Report

Power Systems Engineering Research Center

A National Science Foundation
Industry/University Cooperative Research Center
since 1996

Power Systems Engineering Research Center

Control and Design of Microgrid Components

Final Project Report

Report Authors

Robert H. Lasseter, Project Leader
Paolo Piagi
University of Wisconsin-Madison

PSERC Publication 06-03

January 2006

Information about this project

For information about this project contact:

Professor Robert H. Lasseter:
Department of Electrical and Computer Engineering
University of Wisconsin-Madison
2546 Engineering Hall, 1415 Engineering Drive
Madison, WI 53706
608-262-0186
lasseter@engr.wisc.edu

Power Systems Engineering Research Center

This is a project report from the Power Systems Engineering Research Center (PSERC). PSERC is a multi-university Center conducting research on challenges facing a restructuring electric power industry and educating the next generation of power engineers. More information about PSERC can be found at the Center's website: http://www.pserc.org.

For additional information, contact:

Power Systems Engineering Research Center
Cornell University
428 Phillips Hall
Ithaca, New York 14853
Phone: 607-255-5601
Fax: 607-255-8871

Notice Concerning Copyright Material

Acknowledgements

This is the final report for the Power Systems Engineering Research Center (PSERC) project "Microgrid Protection and Control" (project T-18). The authors express their appreciation for the support provided by the PSERC industrial members and by the National Science Foundation under grant NSF EEC-0119230 received from the Industry / University Cooperative Research Center program. This work was also supported in part by the California Energy Commission (500-03-024).

Executive Summary

Economic, technology and environmental incentives are changing the face of electricity generation and transmission. Centralized generating facilities are giving way to smaller, more distributed generation partially due to the loss of traditional economies of scale. Distributed generation encompasses a wide range of prime mover technologies, such as internal combustion (IC) engines, gas turbines, microturbines, photovoltaic, fuel cells and wind-power. Most emerging technologies such as micro-turbines, photovoltaic, fuel cells and gas internal combustion engines with permanent magnet generator have an inverter to interface with the electrical distribution system. These emerging technologies have lower emissions, and have the potential to have lower cost, thus negating traditional economies of scale. The applications include power support at substations, deferral of T&D upgrades, and onsite generation.

Penetration of distributed generation across the US has not yet reached significant levels. However, that situation is changing rapidly and requires attention to issues related to high penetration of distributed generation within the distribution system. Indiscriminant application of individual distributed generators can cause as many problems as it may solve. A better way to realize the emerging potential of distributed generation is to take a system approach which views generation and associated loads as a subsystem or a "microgrid". This approach allows for local control of distributed generation thereby reducing or eliminating the need for central dispatch. During disturbances, the generation and corresponding loads can separate from the distribution system to isolate the microgrid's load from the disturbance (and thereby maintaining high level of service) without harming the transmission grid's integrity. Intentional islanding of generation and loads has the potential to provide a higher local reliability than that provided by the power system as a whole. The size of emerging generation technologies permits generators to be placed optimally in relation to heat loads allow for use of waste heat. Such applications can more than double the overall efficiencies of the systems.

Most current microgrid implementations combine loads with sources, allow for intentional islanding, and try to use the available waste heat. These solutions rely on complex communication and control, and are dependent on key components and require extensive site engineering. The objective of this work is to provide these features without a complex control system requiring detailed engineering for each application. Our approach is to provide generator-based controls that enable a plug-and-play model without communication or custom engineering for each site.

Each innovation embodied in the microgrid concept (i.e., intelligent power electronic interfaces, and a single, smart switch for grid disconnect and resynchronization) was created specifically to lower the cost and improve the reliability of smaller-scale distributed generation systems (i.e., systems with installed capacities in the 10's and 100's of kW). The goal is to accelerate realization of the many benefits offered by smaller-scale DG, such as their ability to supply waste heat at the point of need (avoiding extensive thermal distribution networks) or to provide higher power quality to some but not all loads within a facility. From a grid perspective, the microgrid concept is attractive because it recognizes the reality that the nation's distribution

system is extensive, old, and will change only very slowly. The microgrid concept enables high penetration of DG without requiring re-design or re-engineering of the distribution system itself**.**

To achieve this, we promote autonomous control in a peer-to-peer and plug-and-play operation model for each component of the microgrid. The peer-to-peer concept insures that there are no components, such as a master controller or central storage unit that is critical for operation of the microgrid. This implies that the microgrid can continue operating with loss of any component or generator. With one additional source (N+1) we can insure complete functionality with the loss of any source. Plug-and-play implies that a unit can be placed at any point on the electrical system without re-engineering the controls. The plug-and-play model facilitates placing generators near the heat loads thereby allowing more effective use of waste heat without complex heat distribution systems such as steam and chilled water pipes.

The microgrid has two critical components, the static switch and the microsource. The static switch has the ability to autonomously island the microgrid from disturbances such as faults, IEEE 1547 events, or power quality events. After islanding, the reconnection of the microgrid is achieved autonomously after the tripping event is no longer present. This synchronization is achieved by using the frequency difference between the islanded microgrid and the utility grid insuring a transient free operation without having to match frequency and phase angles at the connection point. Each microsource can seamlessly balance the power on the islanded microgrid using a power vs. frequency droop controller. This frequency droop also insures that the microgrid frequency is different from the grid to facilitate reconnection to the utility.

This report documents the challenges, problems, and solutions that provide for these important features. The solutions have been fully simulated on software models to test their quality. Then, the control design has been digitally implemented on a hardware setup with two sources here at the University of Wisconsin-Madison, confirming all the theoretical results. With support from the California Energy Commission, a full-scale microgrid will be tested at AEP's Dolan facility midyear of 2006.